opposite charges possibly arriving in great jets from the sun. Further the charges might be communicated to our air from such jets followed by discharge into space beyond.

A sudden uplift of a highly charged thin air layer itself in waves or ridges might easily disturb the normal potential distribution and precipitate discharges from the crests. Atmospheric currents or displacements may cause such uplifts as when a colder stream strikes down under a warmer charged layer.

A set of vertical streamers would deflect a compass needle on the earth's surface one way or the other depending on whether such streamers exist to the north or to the south of the position of the compass. Observations seem to confirm this but more work is needed. The direction of the compass deflection would determine the direction of the virtual streamer currents to which the deflection was due. Aside from these and other considerations, the effort has, however, been to present in this communication a rational theory which will at least enable a proper conception of the actual space relations of the visible portions of an aurora in relation to the earth's surface to be obtained; and to place on record ideas which through many years of consideration by the author have seemingly received at each appearance of an aurora with streamers, repeated confirmation.

While I have in former papers, as in "Thoughts on Osmical Electricity," an address before the Franklin Institute of Pennsylvania (December 19, 1893) and notably in an address on "Atmospheric Electricity" delivered at Princeton University October 21, 1909, and published in *Science*, December 17, 1909, pp. 857 to 869, given a brief sketch of some of the views presented, particularly the outward direction of the streamers, later observations have served to provide cumulative evidence and extend their application.

APPLICATION OF THE LAWS OF ACTION, REACTION AND INTERACTION IN LIFE EVOLUTION

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Since 1893 I have been working upon the interrelations of the various so-called factors of evolution and have published a series of studies of this subject. In 1908 I presented before the American Society of Naturalists an exposition of a law which I termed "the law of the four inseparable factors of evolution," these factors being regarded as the

sum of the forces inherent in environment, in individual development or ontogeny, in race development or heredity, and in natural selection. This conception was worked out more fully in 1912 and published in the form of a preliminary statement, as "Tetraplasy, the Law of the Four Inseparable Factors of Evolution." During the past two years I have been engaged in working out the aspects of this law from the standpoint of physics[1] and chemistry, that is, interchange of energy, in preparation for the Hale Lectures before the National Academy of Sciences on "The Origin and Evolution of Life upon the Earth." I perceive that it was an error to regard Selection as one of the four inseparable factors because it is not a form of energy. Consequently the law should be restated in the following terms:

In each organism the phenomena of life represent the action, reaction, and interaction of four complexes of physico-chemical energy, namely, those of (1) the inorganic environment, (2) the developing individual (cytoplasm and somatic chromatin), (3) the germinal or heredity chromatin, (4) the organic environment. Upon the resultant actions, reactions, and interactions of each organism Selection is constantly operating whenever there is competition with corresponding actions, reactions, and interactions in other organisms.

I believe this to be the most fundamental biologic law which can be expressed from our existing knowledge. It is in part an application to life phenomena, first, of Newton's third law of motion,[2] in the light of which physicists have given the full dynamical meaning to the modern laws of thermodynamics, second, of the laws of thermodynamics, and, third, of Darwin's law of Selection as developed by Weismann, Roux, Osborn, and others in modern biology. The reign of the laws of motion, including the motion of electricity, and of thermodynamics in the life processes follows as a necessary consequence of our modern physio-chemical interpretation of many of the phenomena which were formerly regarded as vitalistic.

This law as operating between two or more organisms may be clearly expressed in the following scheme.

Organism A		*Organisms B—X*
Physico-chemical Actions, Reactions, and Interactions of the LIFELESS ENVIRONMENT	NATURAL SELECTION (Competition, Survival, Elimination, Cessation of Selection, Reversed Selection, Organic Selection, etc.)	Physico-Chemical Actions, Reactions and Interactions of the LIFELESS ENVIRONMENT
DEVELOPING ORGANISM Cytoplasm and Chromatin		DEVELOPING ORGANISM Cytoplasm and Chromatin
HEREDITY CHROMATIN		HEREDITY CHROMATIN
LIFE ENVIRONMENT		LIFE ENVIRONMENT

Physico-chemical actions and reactions, which, so far as known, follow the laws of conservation of energy, are the chief phenomena observed in modern physiology, as set forth in such works as Loeb's "Dynamics of Living Matter." Through catalysis many of the actions and reactions are known to send off chemical messengers which are among the chief means of interaction in different parts of the organism. There are in animals other means of interaction, such as the enzymes, the secretions of the duct glands, the internal secretions of the ductless glands, and the nervous system. These interactions do not follow the laws of conservation of energy; they work at a distance, and the effects do not balance the causes. Certain phenomena of interaction, in which chemical messengers of various kinds coördinate the actions and reactions of the organism, are now understood both in physiology and pathology as coördinating, correlating, accelerating (hormones), and retarding (chalones), as well as balancing growth and development.

The nature of the actions, reactions, and interactions between the physical environment, the development organism, and the life environment are relatively well understood. It remains to be determined what relations these actions, reactions, and interactions respectively have to the physico-chemical processes in the somatic and in the germinal chromatin. There are some grounds for the hypothesis of Cunningham that some of these chemical messengers affect in a similar manner the germinal and bodily chromatin, but this subject is very obscure at present.

[1] I am indebted to my colleague M. I. Pupin for valuable suggestions in formulating the physical aspect of these principles. He regards Newton's third law as the foundation not only of modern dynamics in the Newtonian sense but in the most general sense, including biological phenomena. The second law of thermodynamics started from a new principle, that of Carnot, which apparently had no direct connection with Newton's third law of motion. This second law, however, in its most general form cannot be fully interpreted except by statistical dynamics, which is a modern offshoot of Newtonian dynamics. With regard to the first law of thermodynamics, it is a particular form of the principle of conservation of energy as applied to heat energy. Helmholtz, who first stated the principle of conservation of energy, derived it from Newtonian dynamics.

[2] "I. Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon."

"II. The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed."

"III. To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts."

"Newton's Principia; the Mathematical Principles of Natural Philosophy, by Sir Isaac Newton," translated into English by Andrew Motte, publ. Daniel Abbe, New York, 1848, pp. 83–84.